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Agriculture, Climate Disruption, and Carbon Sequestration

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Contents

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Estimates show that, in 2019, agriculture production contributed about 9.6% of the total greenhouse gas (GHG) emissions by all sources in the United States. Carbon sequestration and reductions in GHG emissions can occur through a variety of agriculture practices and systems of production. This publication presents an overview of the relationships between agriculture, climate disruption, and carbon sequestration. It investigates possible options for farmers and ranchers to both adapt to and mitigate the impact of a changing climate. The challenges and opportunities of evolving agriculture carbon markets are also explored briefly.

This publication uses the term ***climate disruption*** because its focus is on the disrupting nature of a changing climate for agricultural production systems.

Cover crop plots in the Rio Grande Valley. Cover crops help to fix nitrogen into soils using legumes and thus reduce GHG emissions related to synthetic fertilization. Photo: Mike Morris

Introduction: The Earth is Warming

According to the most recent (2021) research by the Intergovernmental Panel on Climate Change (IPCC), it is "unequivocal that human influence has warmed the atmosphere, ocean, and land. Widespread and rapid changes in the atmosphere, ocean, cryosphere [Earth's frozen water], and biosphere have occurred." In this same report, the IPCC estimated that the "global surface temperature in the first two decades of the 21st century (2001-2020) was 0.99°C [1.78°F] higher than 1850-1900."

The IPCC also projects that compared to this same mean baseline of 1850 to 1900, global surface temperature could range from 1.0°C [1.8°F] to as much as 5.7°C [10.26°F] higher by sometime within 2081-2100 (IPCC, 2021), depending on various scenarios estimating how GHGs will or will not be reduced in the future.

These changes include two major implications for agriculture:

- With every additional increment of global warming, changes in weather extremes continue to become larger. For example, every additional 0.5°C of global warming causes clearly discernible increases in the intensity and frequency of hot extremes, including heatwaves *(very likely),* and heavy precipitation *(high confidence),* as well as agricultural and ecological droughts in some regions *(high confidence)* (IPCC, 2021).
- It is *very likely* that heavy precipitation events will intensify and become more frequent in most regions, given additional global warming. At the global scale, extreme daily precipitation events are projected to intensify by

about 7% for each 1°C of global warming *(high confidence)*. The proportion of intense tropical cyclones/hurricanes (categories 4 to 5) and peak wind speeds of the most intense tropical cyclones/hurricanes are projected to increase at the global scale with increasing global warming *(high confidence)* (IPCC, 2021).

Although these most recent estimates of global climate disruption due to human activity are significant and concerning, it is important to realize that these broad impacts will vary across regions of the earth and within the United States.

The Greenhouse Effect

Although natural shifts in global temperatures have occurred throughout human and natural history, scientists attribute the present temperature increase to a rise in carbon dioxide and other greenhouse gases released from the burning of fossil fuels, deforestation, agriculture, and other industrial processes. Scientists often refer to this phenomenon as the *enhanced greenhouse effect.*

The naturally occurring greenhouse effect traps the heat of the sun before it can be released back into space. This allows the Earth's surface to remain warm and habitable. However, increased levels of greenhouse gases enhance the naturally occurring greenhouse effect by trapping even more of the sun's heat, resulting in a global warming effect. Figure 1 illustrates the natural and enhanced greenhouse effects.

The primary greenhouse gases associated with agriculture are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Although carbon dioxide is the most prevalent and long-lived greenhouse gas in the atmosphere, nitrous oxide and methane absorb significantly more radiation energy in their shorter lifetimes. Thus, nitrous oxide and methane are considered especially potent global warming gases.

Several excellent resources and fact sheets explain the greenhouse effect and the science behind climate disruption. See the Further Resources section for information.

How Does Climate Disruption Influence U.S. Agriculture and Rural Communities?

Climate disruption may have significant consequences for U.S. agriculture. The U.S. Global Change Research Project released its

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Biodiesel: The Sustainability Dimensions

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Energy Saving Tips for Irrigators

Federal Working Lands Conservation Resources for Sustainable Farming and Ranching

Payments for Ecosystem Services

Renewable Energy Opportunities on the Farm

Figure 1. The Greenhouse Effect. Source: Marion Koshland Science Museum of The National Academy of Sciences

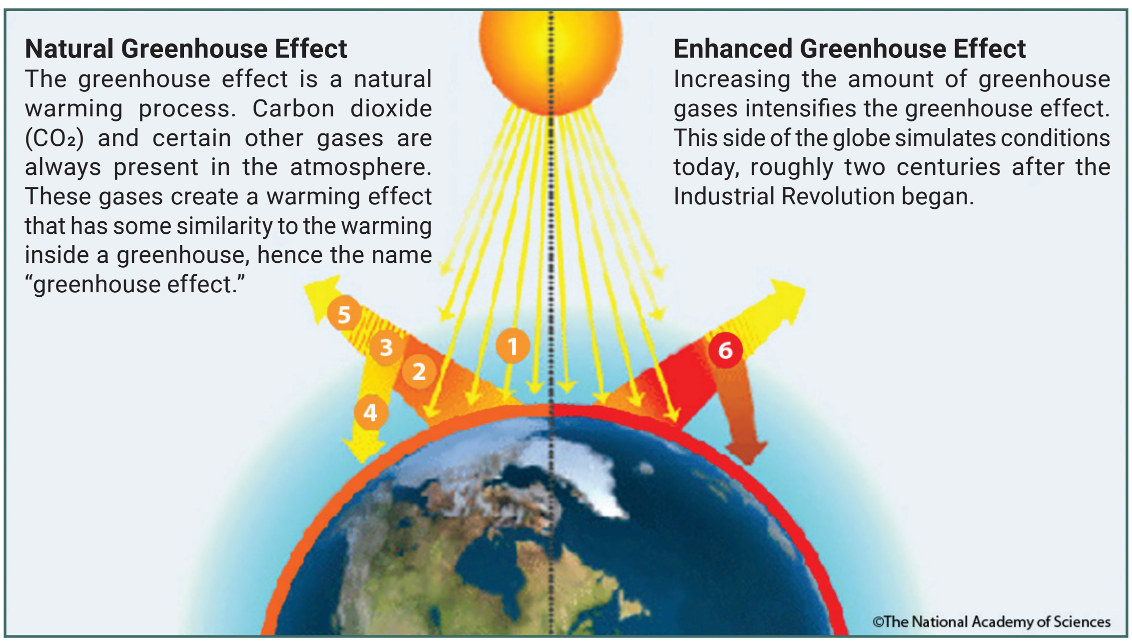


Illustration of the greenhouse effect. Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth (1) is absorbed and converted to heat, which warms the surface. The surface (2) emits infrared radiation to the atmosphere, where some of it (3) is absorbed by greenhouse gases and (4) re-emitted toward the surface; some of the heat is not trapped by greenhouse gases and (5) escapes into space. Human activities that emit additional greenhouse gases to the atmosphere (6) increase the amount of infrared radiation that gets absorbed before escaping into space, thus enhancing the greenhouse effect and amplifying the warming of the earth.

Fourth National Climate Assessment Report in 2018 and focused an entire chapter on agriculture and rural communities. According to this assessment, there are four key impacts of climate disruption on U.S. agriculture:

- Reduced agricultural productivity due to drought, shifting precipitation patterns, higher temperatures, wildfires, depleted water supplies for irrigation, and expanded distribution and incidence of pests and diseases (p. 392)
- Degradation of soil and water resources due to extreme precipitation events, excessive water runoff, leaching, soil erosion from flooding, and degraded water quality in lakes and rural infrastructure (p. 392)
- Health challenges to rural populations and livestock due to increased frequency and intensity of high-temperature extremes, resulting in heat exhaustion and heatstroke (p. 393)
- Limited capacity of rural residents to respond to climate impacts, due to rural poverty and lack of community resources (p. 394)

Again, these overall impacts will vary across regions within the United States. To learn more about these varying regional impacts, the USDA has established 10 regional Climate Hubs, which provide specific information about climate impacts in each of these regions. The Internet link to each Climate Hub can be found at climatehubs.usda.gov.

How Does U.S. Agriculture Influence Climate Disruption?

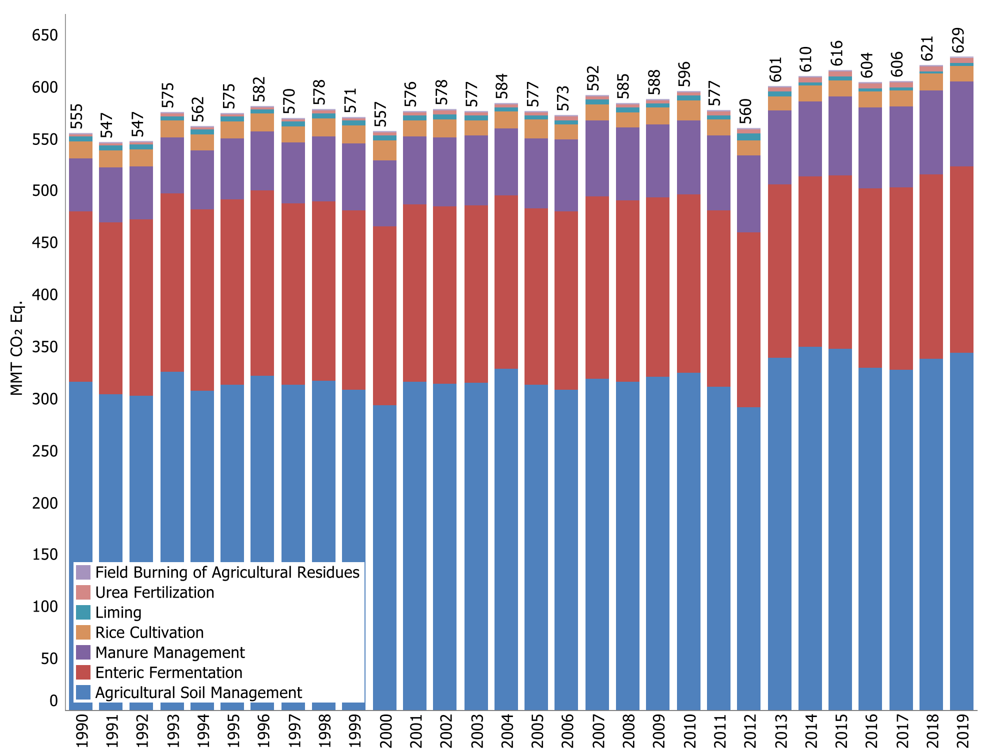
Agriculture's Contribution to Greenhouse-Gas Emissions

Agriculture activities serve as both sources and sinks for greenhouse gases. Agriculture sinks of greenhouse gases are reservoirs of carbon that have been removed from the atmosphere through the process of biological carbon sequestration.

The primary sources of GHG emissions from agriculture from 1990 to 2019 are shown in Figure 2. The major sources derive from the way agricultural soils and manure are managed and from enteric fermentation by ruminant animals. Smaller amounts of GHG emissions are caused by the way rice is cultivated, liming of agriculture soils, urea fertilization, and field burning of crop residues. In 2019, GHG emissions from U.S. agriculture were estimated to be about 9.6 % of all U.S. GHG emissions (U.S. EPA, 2021).

Direct GHG emissions from soil management are principally N_2O emissions from synthetic fertilization, application of managed livestock manure, application of other organic materials (such as biosolids), deposition of manure on soils by domesticated animals, retention of crop residues, and drainage of organic soils. Other soil-management activities with GHG emission impacts include irrigation, drainage, tillage practices, cover crops, and fallowing of land, which can influence nitrogen mineralization from soil organic matter (U.S. EPA, 2021). Sources of indirect emissions from agricultural soil management include loss of nitrogen to the atmosphere, surface runoff, and leaching into ground and surface waters (U.S. EPA, 2021).

Figure 2. Greenhouse Gas Emissions Related to Agricultural Activities, 1990-2019 (MMTCO2 equivalent). Source: EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2019



GHG emissions due to enteric fermentation derive from the release of methane in the natural digestion processes of principally ruminant livestock (beef cattle, dairy cattle, buffalo/bison, sheep, and goats). Non-ruminant livestock, such as swine, horses, and mules, also release some methane through digestive processes but at a significantly lower volume.

Releases of GHG emissions in the form of CH_4 and N_2O derive from the treatment, storage, and transportation of livestock manures. CH_4 is produced from the anerobic decomposition of manure and N_2O is the result of the processes of nitrification and denitrification. There are various ways that GHG emissions are released, depending on how manure is managed and/or treated: lagoons, ponds, tanks, or pits.

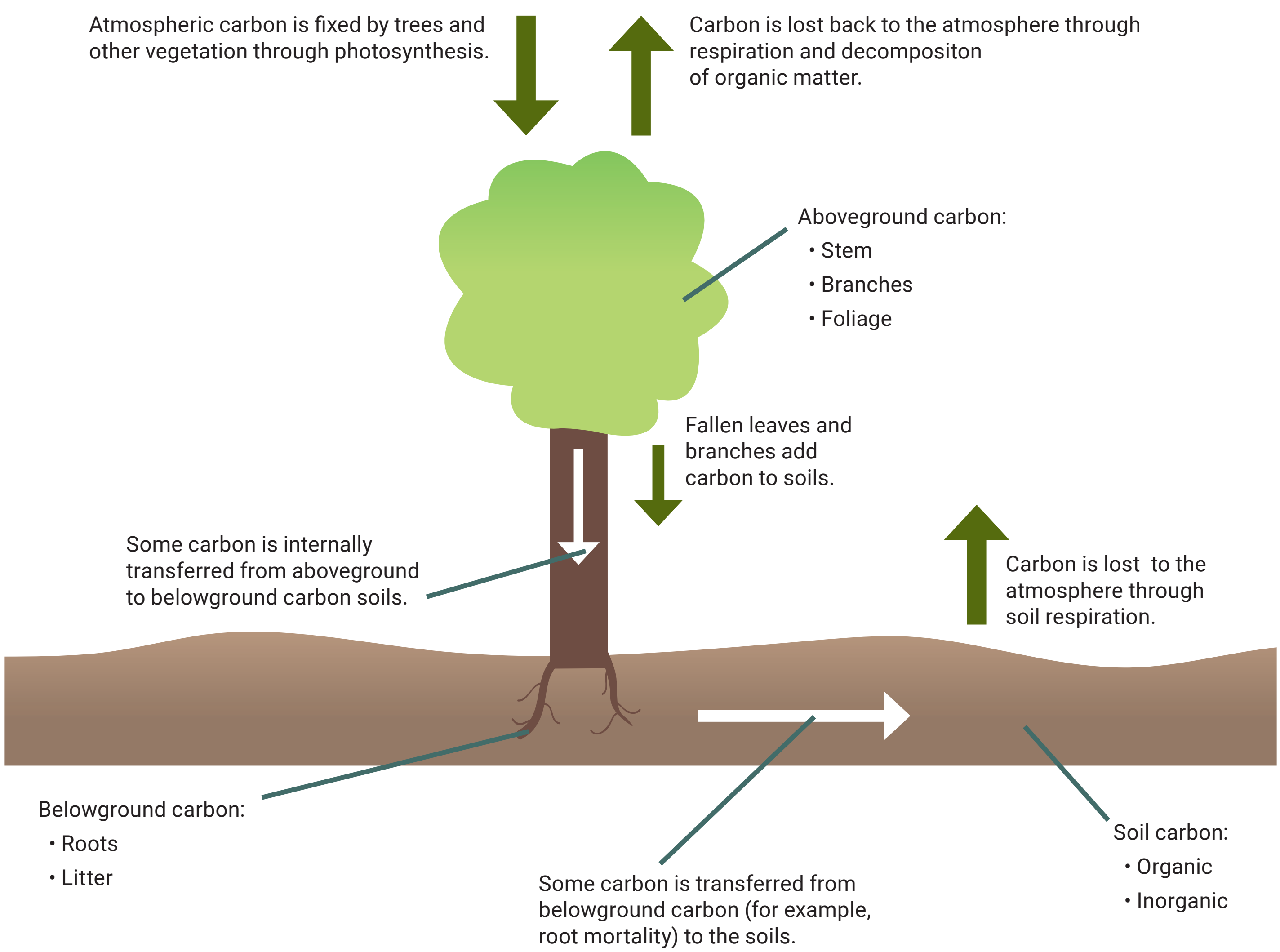
Carbon Sequestration

Carbon sequestration in the agriculture sector refers to the capacity of agricultural lands and forests to remove carbon dioxide from the atmosphere and store it. Carbon dioxide is absorbed by trees, plants, and crops through photosynthesis and stored as carbon in biomass of tree trunks, branches, foliage, roots, and soils. Forests and stable grasslands are referred to as carbon sinks because they can store large amounts of carbon in their vegetation and root systems for long periods of time. Soils are the largest terrestrial sink for carbon on the planet. The ability of agricultural land to store carbon depends on several factors, including climate, soil type, type of crop or vegetation cover, and management practices.

Figure 3 illustrates the different processes through which trees and soils can gain and lose carbon.

Changes in the way land is used can also alter the store (sink) of sequestered carbon in agricultural lands. For instance, if grasslands are converted

Figure 3. Carbon Pools in Forestry and Agriculture. Source: U.S. Environmental Protection Agency



to human settlement (cities) or cropland, some of the stored soil carbon in those grasslands will be released. These types of changes are referred to as GHG emission *fluxes,* which are a measure of the net change (positive or negative) in carbon stores or sinks. A measurement of this change is called Land Use, Land Use Change, and Forestry, or LULUCF. For the United States from 1990 to 2019, these changes have led to a net loss of about 111.6 million metric tons of CO_2 equivalent ($MMTCO_2eq$) in GHG emissions. Although they represent a significant loss of carbon, the sources of GHG emissions estimated in Figure 2 are much more significant in aggregate.

Agriculture's Role in Mitigating Climate Disruption

There are several ways to change agricultural production practices and systems to prevent further climate disruption. Broadly, these include enhancing carbon storage in soils, preserving existing soil carbon levels, and, of course, reducing carbon dioxide, methane, and nitrous oxide emissions in agricultural production.

Following are several major options estimated to have the greatest potential for mitigating the climate-disruptive impacts of agriculture on a global scale (Bossio et al., 2020; Griscom et al., 2017). They are broken down into three groups: soil carbon, mixed, and GHG emission-reduction impacts.

Soil Carbon Sequestration Impacts

Avoided Forest Conversion and Reforestation Promotion

Though not directly related to agricultural production processes, clearing forests to expand crop or livestock production can lead to loss of the forestland's substantial soil carbon storage, which is an important offset for GHG emissions generally. Efforts to conserve or plant forests have additional benefits of improving soil water retention and flood control. These efforts are estimated to provide up to 1.2 gigatons (1.2 billion metric tons) per year of CO_2 equivalent in soil carbon storage and mitigation (Bossio et al., 2020).

Avoided Grassland Conversion

Like avoided forest-land conversion, avoiding the conversion of grasslands to cropland can prevent loss of soil carbon storage. Permanent grasslands can also assist with flood control and improve soil water-holding capacity, with additional benefits to wildlife. Avoiding grassland conversion provides an estimated 0.23 GT CO_2 eq. per year of additional carbon storage (Bossio et al., 2020).

Agroforestry

Integrating trees and shrubs into cropping and/or livestock systems can help stabilize soil carbon storage and reduce soil erosion. Additional benefits include increased biological production, improved water quality, water recharge, capture of airborne particles and pollutant gases, and improved wildlife habitat. The increase of agroforestry has been estimated to provide 0.28 GT CO2 eq. per year in added carbon storage (Bossio et al., 2020). For more information, see the ATTRA publication *Agroforestry: An Overview* and *ATTRA Voices from the Field* podcast episodes 187 and 188.

Optimal Grazing Intensity

Adopting grazing practices that decrease stocking rates in areas that are currently overgrazed, while increasing stocking rates in grazing areas that are not optimized, could improve soil carbon storage. These changes may also have a benefit in reducing water use on pastures. These efforts could provide 0.15 GT CO_2 eq. per year in soil carbon storage (Bossio, 2020). For more information, consult the ATTRA publication *Building Healthy Pasture Soils.*

Mixed Soil Carbon Sequestration and GHG Emission Reduction

Biochar

Biochar is a soil amendment that is created by converting sustainably harvested biomass through a process known as pyrolysis. Pyrolysis is the combustion of biomass in the near absence of oxygen. This combustion creates not only biochar but also additional oils and gases that can function as biofuel.

Although the application of biochar to agricultural soils is growing worldwide, its application in U.S. agriculture has been limited. The potential to build

There are several ways to change agricultural production practices and systems to prevent further climate disruption, including enhancing carbon storage in soils, preserving existing soil carbon levels, and reducing carbon dioxide, methane, and nitrous oxide emissions in agricultural production.

soil organic carbon through biochar application is significant. In addition, biochar application can potentially increase fertility while reducing the need for synthetic fertilizers (an important source of GHG emissions), helping soil retain moisture, and reducing soil acidification. Expanded use of biochar can provide an estimated 1.1 GT CO_2 eq. per year in direct mitigation (Bossio et al., 2020). For more information on biochar, see the ATTRA publication *Biochar and Sustainable Agriculture.*

Cover Cropping

A cover crop is any crop grown to provide soil cover, regardless of whether it is later incorporated into the soil. The climate benefits of cover crops are related to their prevention of soil erosion by wind and water, use as a green manure (fixing nitrogen into soils using legumes and thus avoiding or reducing GHG emissions related to synthetic fertilization), and maintenance or increase of soil organic matter generally. Additional benefits include improving soil moisture efficiency, minimizing soil compaction, suppressing weed pressures, breaking pest cycles, and improving water quality by trapping excessive soil nutrients (NRCS, 2014). The use of cover cropping provides an estimated 0.41 GT CO_2 eq. per year (Bossio et al., 2020). For more information on cover cropping, see several ATTRA publications on this topic listed in the Further Resources section of this publication.

The benefits of cover crops are prevention of soil erosion, use as a green manure, increase of soil organic matter, improving soil moisture efficiency, minimizing soil compaction, suppressing weed pressures, breaking pest cycles, and improving water quality by trapping excessive soil nutrients.

Integrating Legumes into Pastures and Grazing Lands

Additional soil carbon sequestration could be added by sowing legumes into pastures and grazing lands. This can also result in improved soil health and the increased use of biological nitrogen fixation, rather than synthetic fertilizer associated with GHG emissions. This practice could add up to an estimated 0.15 GT CO_2 eq. per year in soil carbon storage.

GHG Emission Reduction

Soil Nutrient Management

As noted above, N_2O emissions from soil management are the single most important source of GHG emissions from agriculture. There are many ways to better manage soil fertility, such as careful use of synthetic fertilizers, green manuring, crop rotations, cover cropping, and tillage.

Irrigation and Water Management

Improvements in water-use efficiency through measures such as irrigation-system advances, drip irrigation technologies, and center-pivot irrigation systems, coupled with a reduction in operating hours, can significantly reduce the amount of water and nitrogen applied to the cropping system. This reduces both greenhouse emissions of N_2O and water withdrawals. For more information, see the ATTRA publication *Energy Saving Tips for Irrigators.*

Biofuels

There is significant scientific controversy regarding whether biofuels—particularly those derived from oilseeds (biodiesel), feed corn (ethanol), or even from cellulosic sources—are carbon neutral. To ascertain the true climate neutrality of biofuels requires a careful life-cycle analysis of the specific biofuel under consideration. Also, an analysis is needed to understand what the global land-use change implications will be if farmers grow more of a specific biofuel feedstock. For further information on biofuels, see the ATTRA publication *Biodiesel: The Sustainability Dimensions.*

Other Renewable Energy Options

Renewable energy, such as wind, solar, and micro-hydro, also presents significant opportunities for the agriculture sector to reduce GHG emissions. For further information about these options, see the ATTRA publication *Renewable Energy Opportunities on the Farm.*

The Value of Soil Carbon: Potential benefits for farmers and ranchers

As Mazza (2007) has remarked, "[C]reating farm and forestry systems with strong incentives for growing soil carbon could well be at the center of climate stabilization." Thus, a new product that farmers and ranchers may offer in the future is carbon. The Natural Resources Conservation Service (NRCS), part of the USDA, has long been a promoter of managing carbon in efforts to improve soil quality.

As with any product, farmers and ranchers need a market for carbon, as well as a price that will make it profitable to produce. From a broader social context, the questions of who will purchase carbon products and what is a fair price are also important. Many voluntary agricultural private carbon schemes exist in the United States as of the date of this publication (2021). The ATTRA publication *Payments for Ecosystem Services* offers a current (2020) review of these agriculture carbon schemes.

Beyond these schemes, the topic of how to value and ultimately establish a price for carbon from the perspective of the individual farmer and rancher, as well as society at large, is at the heart of understanding the role agriculture can play in carbon sequestration and climate stabilization.

The two most frequently discussed systems to create value for offsetting GHG emissions and carbon storage are carbon taxation and cap and trade. Government subsidies are discussed less often but will also play a role in GHG emission reductions and soil carbon sequestration.

Charge Systems: Carbon Tax

Taxing every ton of carbon in fossil fuels, or all the tons of GHG emissions, gives entities that emit GHGs or use fossil carbon-based fuels an incentive to switch to alternative renewable fuels, invest in technology changes to use carbon-based fuels more efficiently, and, in general, adopt practices that would lower their level of GHG emissions. Thus, a carbon or GHG emissions tax values carbon in negative terms of tax avoidance. For example, those farms and ranches that emit less carbon or use less carbon-intensive fuels pay a smaller tax.

From the perspective of farmers and ranchers, a carbon tax would increase the direct and indirect costs of agricultural production. Farmers and ranchers use carbon-based fuels directly in the forms of petroleum and natural gas and indirectly in the forms of fossil carbon-based fertilizers and pesticides and other fossil fuel-intensive inputs. Consequently, a carbon tax could incentivize farmers and ranchers to shift to systems of production that either eliminate the use of fossil fuels and inputs or at least improve the efficiency of their use.

However, proponents of carbon taxes have generally sought to exclude the agriculture sector from such taxation. For the most part, carbon tax proponents have been more interested in placing GHG emission taxes on upstream producers of the original source products. These includes coal, petroleum, and natural gas producers and major emitters, such as large electric utilities. Nonetheless, as people work to reduce GHG emissions, placing a carbon tax on sectors like agriculture could be considered.

Benefits of a Carbon Tax for Farmers and Ranchers

A major benefit of a carbon or GHG emissions tax would be a stream of tax revenue that the government could use to further induce the practice and technology changes necessary to lower GHG emissions and sequester carbon. For example, many of the current agricultural conservation programs, such as the Environmental Quality Incentives Program (EQIP) and the newer Conservation Stewardship Program (CSP), support improvements in soil quality. These programs could be funded in part from emission or carbon taxes, thereby providing a revenue source to subsidize those who adopt or maintain emission-reduction practices or carbon sequestration activities. See the ATTRA publication *Federal Resources for Sustainable Farming and Ranching* for more information.

A major benefit of a carbon or GHG emissions tax would be a stream of tax revenue that the government could use to further induce the practice and technology changes necessary to lower GHG emissions and sequester carbon.

Tax revenues could also assist in supporting conservation programs like the Conservation Reserve Program (CRP). CRP works to keep sensitive and highly erodible lands out of production. These lands sequester soil carbon.

Another benefit of the carbon-tax approach is that a tax provides a clear and stable cost to current practices. A tax also makes it easier to determine changes that will be more profitable in a new cost environment. For instance, if a concentrated animal feeding operation (e.g., a feedlot or large commercial dairy) understood the cost of its emissions as expressed by its GHG emission tax, it would be easier for the operation to determine alternatives to current practices that would be cost efficient. At a high enough tax rate, installing methane digesters to lower GHG emissions would become more economically feasible and would not require government subsidization. Also, a high GHG emission tax rate may make alternative livestock production systems, such as grass-finished ruminant production, more economical, thereby reducing the need for confined animal feeding.

Finally, supporters argue that a carbon-tax approach is cost-effective in implementation, at least when compared to the cap-and-trade method of achieving GHG emission reductions. As a (somewhat dated) Congressional Budget Office report said: “available research suggests that in the near term, the net benefits (benefits minus costs) of a tax could be roughly five times greater than the net benefits of an inflexible cap" (Congressional Budget Office, 2008).

Downside of a Carbon Tax

Introducing any tax results in discussions of where the burden of taxation lies and raises issues of equity. In short, taxation is about who pays and who does not. New taxes also often result in a public discussion of the fairness of the tax. There is logic to the argument that the burden of a carbon and/or GHG emissions tax should be placed first and foremost on those who either create carbon-intensive fuels or those who are the largest emitters of GHG. The greatest source of GHG emissions in the United States is combustion of fossil fuels. Because agriculture represents a small percentage of total U.S. fossil fuel use, an argument can be made that the burden of taxation would not fall too significantly on this sector. Still, agriculture is heavily dependent on fossil fuels, and any carbon or GHG emission tax would likely be costly.

The greatest source of GHG emissions in the United States is combustion of fossil fuels.

The ability of any individual farmer or rancher to pass on the increased costs of fossil fuels that this kind of taxation would create is much more limited than in other sectors of the economy. For instance, if a carbon tax is placed on diesel fuel, diesel fuel manufacturers can more easily pass on the tax burden to the consumers of the diesel. The ability to pass on costs to consumers is greater in industries where there is little product substitution and where a few producers dominate the market. (In economics, these entities are known as oligopolies.) This is not the case for farmers and ranchers, given their relative lack of market concentration and economic power.

Cap and Trade: A Market for GHG Emissions

A government-sponsored cap-and-trade system would create a new national market for GHG emissions by establishing a new property right—the right to emit. The market is created by a government that sets a limit or cap on total GHG emissions allowed. Companies that emit greenhouse gases are issued permits for a specified amount of emissions. Companies and groups that exceed their allowed emissions must purchase offsets from other entities that pollute less than their allowance or from entities that sequester carbon.

These exchangeable emission permits, often called allowances, are measured in tons of carbon dioxide equivalents per year. Carbon dioxide equivalents provide a common measure for all GHG emissions and are calculated by converting greenhouse gases into carbon dioxide equivalents according to their global warming potential.

Over time, the government will continually lower the total level of allowances available to meet an established level of acceptable total emissions. As the supply of allowances decreases, the value of the allowances will rise or fall depending on demand and on the ability of emitters to make necessary changes to reduce emissions or purchase offsets from groups more capable of reducing emissions.

Benefits for Farmers and Ranchers

Depending on the practices adopted, farmers and ranchers could be a source of inexpensive carbon reductions and thus capture the value of these allowances as offsets. In short, the value of offsets would become the market price of carbon equivalents. This would become the value of the new crop—carbon—that those farmers and ranchers could produce.

A limited, privately created, and voluntary cap-and-trade system called the Chicago Climate Exchange (CCX) was created in 2003 and failed in 2011. The emission cap was set by emitting entities that voluntarily sought to limit their GHG emissions. Purchases of agriculture offsets had been part of this exchange. The value of GHG emission credits was never high enough or stable enough to warrant the minimum necessary participation by farmers and ranchers. Farmers and ranchers who did participate suffered economic losses due to the collapse of this market. A similar cap-and-trade market was established in California and is still in operation as of 2021. It does not recognize agriculture-related offsets, except for methane digesters related to dairy operations, because of the difficulty of measuring, verifying, and monitoring the offsets provided.

Downsides of Cap and Trade

To provide carbon offsets for GHG emitters, farmers and ranchers must be willing to make long-term, or even permanent, changes in not only practices but perhaps whole systems of production. These changes also need to be verified to result in true offsets of GHG emissions. The issues of verifiability, permanence, and what is known as additionality are critical to the success of agriculture's role in the cap-and-trade system and the ultimate reduction of greenhouse gas emissions.

Verifiability is critical because the system or practice change must result in a measurable change in the amount of carbon stored or GHG emitted. For example, the adoption of a no-till cultivation practice is thought to result in soil with higher carbon sequestration capacity. However, there is continuing scientific debate over whether the practice of continuous no-till does in fact lead to long-term additional storage of carbon in the soil (Baker et al., 2007).

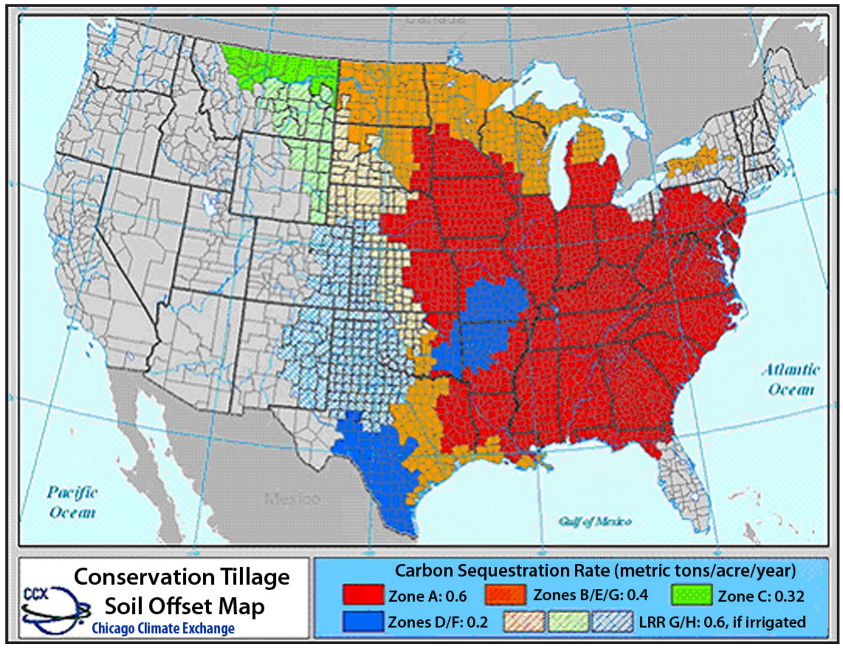
Another example comes from the failed CCX experience, in which agricultural cropping areas in the United States were divided into zones and allocated specific levels of carbon sequestration to each acre farmed in a particular zone under continuous no-till practices.

While there may be some need to simplify the implementation of a nationwide soil carbon sequestration project related to tillage practice change, it is very doubtful that the actual carbon storage levels allocated can be achieved across areas that are so large. Finally, the failed CCX did not verify the actual carbon storage resulting from the practice change, but only monitored that the practice was maintained during the life of a limited contract period. Thus, it is doubtful that the carbon offset truly matched actual carbon sequestered. Such issues, in part, were related to the failure of the CCX.

The issue of permanence is also critical. What happens after a farmer or rancher changes to a practice or system of production, is paid for carbon stored, and then decides to change practices again and potentially releases the carbon that he was paid to sequester?

Additionality refers to the issue that a farmer or rancher can only offer and be paid for an offset for a new sequestration of carbon, not for a practice or a system of production already in place. For instance, if a rancher developed a permanent wind shelterbelt, that change in land use would likely result in new, or additional, carbon sequestration. However, a rancher who had already developed a similar shelterbelt would not be eligible for an offset because the rancher would not be providing additional carbon sequestration. Likewise, a farmer already engaged in conservation tillage

Figure 4. Conservation Tillage Soil Offset Map. Source: Chicago Climate Exchange



would not provide additional carbon storage by maintaining that practice. However, the current USDA Conservation Stewardship Program (CSP) provides a possible payment structure that pays farmers to maintain such practices.

Additionality is also important because of the possibility that perverse incentives may be created that encourage farmers or ranchers to release carbon so that they can get paid to store it. For example, a farmer practicing no-till farming may decide to abandon the practice because of the new availability of per-acre payments and later switch back to no-till. To address this and stop additional GHG emissions, the idea of offsets would need to be expanded to include farmers and ranchers already undertaking a practice or specific land use that stores soil carbon, or the program would have to create an extra fund of emission credits to cover such losses.

Subsidizing Positive Behavior

A final mechanism that could expand the ability of the agriculture sector to mitigate GHG emissions is one that is already well known—a direct subsidy. Many federal conservation programs provide incentives, known as cost shares or income support, that help farmers and ranchers make changes in practices to conserve natural resources. For more information, see the ATTRA publication *Federal Resources for*

Sustainable Farming and Ranching. For example, data in Table 1, adapted from a Natural Resources Conservation Service bulletin, indicates various crop and animal management practices that can either lower GHG emissions or increase carbon sequestration. Under the Conservation Stewardship Program and the Environmental Quality Incentives Program, farmers and ranchers can receive payments to adopt new practices or receive support to maintain such practices. Though they are not yet designed to address climate change issues specifically, many federal conservation programs already provide public incentives to reduce GHG emissions.

Refocusing federal conservation programs could lower GHG emissions and increase carbon sequestration. Perhaps modifications of the Conservation Stewardship Program and the Environmental Quality Incentives Program could allow for longer contracts (currently a maximum of five years), so that outcomes are reached and maintained. Also, the programs could add specific validation procedures to assure climate targets are met and sustained.

Benefits of Subsidies

With this approach, there is an immediate benefit to farmers and ranchers willing to make changes that meet the challenges of climate stabilization. If programs are sufficiently funded for outreach and technical assistance, efforts can be made to assure that all farmers and ranchers—regardless of their situation—take advantage of these programs. Finally, resources can be prioritized to different regions of the country—or to specific practices or systems of production—so programs can be cost-effective in reaching climate disruption goals.

Table 1. Agricultural Practices and Benefits. Source: USDA Natural Resources Conservation Service

Conservation Practice	GHG Objectives	Additional Benefits
CROPS		
Conservation tillage and reduced field pass intensity	Sequestration, emission reduction	Improves soil, water and air quality. Reduces soil erosion and fuel use.
Efficient nutrient management	Sequestration, emission reduction	Improves water quality. Saves expenses, time and labor.
Crop diversity through rotations and cover crops	Sequestration	Reduces erosion and water requirements. Improves soil and water quality.
ANIMALS		
Manure management	Emission reduction	On-farm sources of biogas fuel and possibly electricity for large operations, provides nutrients for crops.
Rotational grazing and improved forage	Sequestration, emission reduction	Reduces water requirements. Helps withstand drought. Increases long-term grassland productivity.
Feed management	Emission reduction	Reduces quantity of nutrients. Improves water quality. More efficient use of feed.

Downside of Subsidies

Subsidies are a public cost, and utilizing this approach requires a good understanding of the value of such public investment. Furthermore, subsidies are based on the idea that the government can know and assure that the practices it pays for to achieve the intended outcomes. For example, the federal government provides significant subsidization of corn ethanol production. Many argue that this changed the price of field corn and increased costs for people who use corn as animal feed and for other countries that import corn to feed people. There are also questions about how subsidies can reduce GHG emissions and impact soil carbon sequestration changes. Will subsidizing a shift to a continuous no-till cultivation result in greater carbon sequestration? If the scientific understanding of the relationship between carbon sequestration and no-till is simply or even partially in error, then public dollars spent to change farmer behavior could be wasted. Furthermore, will subsidization offer the least expensive way to achieve specific outcomes?

For example, researchers in 2006 estimated that it would take a price of at least $13 per ton of carbon dioxide equivalent ($50 per ton of carbon) per year to offset 70 million metric tons (MMT) of carbon dioxide equivalents. This would have resulted in an estimated total public cost of close to $1 billion dollars per year for perhaps as long as 40 years. Also, this change represented an estimated offset of only 4% of total U.S. GHG emissions in 2004. Was this the least expensive way to reduce GHG emissions compared to alternative public expenditures? For instance, what if public dollars were committed to a research program to improve the gas mileage of automobiles?

Finally, how do we know that this research correctly estimates the incentive needed to change farming and ranching practices? In a 2018 analysis, the authors suggested that carbon prices "currently range from $3.30 to $150 per ton CO_2e depending on region and whether markets are voluntary or compliance" (Agribusiness Consulting, 2019). This is a very wide range of prices, which begs the question of what is the "correct," much less "fair," price for carbon.

Another related example of the issue of understanding carbon pricing comes from the Natural Resources Conservation Service (NRCS) in Montana. A sophisticated USDA-supported modeling tool called COMET Planner estimated that the carbon sequestration potential of adopting cover crop practices in Montana was about 0.22 ton of CO_2 eq. per acre per year. A private company, Indigo Agriculture, is providing $15 per ton of carbon sequestered, which in this case would provide a payment of about $3.30 per acre to adopt a cover cropping practice (Indigo, 2021). Interestingly, Montana NRCS will assist farmers to adopt a multi-species cover crop to the tune of $15.41 per acre. So, what price of carbon is best to motivate the adoption of cover cropping in Montana? Is Montana NRCS paying too much or is Indigo Agriculture paying too little?

While the difference between these examples might be explained by regional variation in carbon sequestration capacity and how sequestration is accomplished, the point is that public costs would nonetheless be significant to achieve GHG emission reductions through subsidization.

Subsidies are based on the idea that the government can know and assure that the practices it pays for achieve the intended outcomes.

Summary

The public sector will play an important role in determining how to engage the agriculture sector in the reduction of GHG emissions and stabilization or improvement in carbon sequestration. The federal government can use its power to tax, subsidize, or create a new market mechanism to do this. In 2008, the U.S. Senate debated climate change legislation, including the Lieberman-Warner bill. This bill proposed a modified cap-and-trade system with the expectation that the agriculture sector would provide at least 15% of the offsets needed to reduce GHG emissions 71% from 2005 levels by 2050. Unfortunately, that effort failed to address future climate disruption. Today, many proposals have been offered, proposing that by 2030 the agriculture sector could be a net-zero emitter of GHG emissions or contribute increasing levels of soil carbon sequestration to offset its emissions. Whether these proposals or future legislation will become the basis of future climate disruption improvements is an open question. However, there is little doubt that agriculture will play some role in these efforts.

References

Agribusiness Consulting. 2019. Economic Assessment for Ecosystem Service Market Credits from Agricultural Working Lands. Report prepared for the Ecosystems Services Market Consortium, LLC. globalaginvesting.com/wp-content/uploads/2021/08/HQ-Carbon-White-Paper-V4.pdf

Baker, J.M., T.E Ochsner, R.T. Venterea, and T.J. Griffis. 2007. Tillage and Soil Carbon Sequestration—What Do We Really Know? Agriculture, Ecosystems and Environment. Vol. 118. p. 1-5.

Bossio, D. A., S.C. Cook-Patton, P.W. Ellis, J. Fargione, J. Sanderman, P. Smith, S. Wood, R. J. Zomer, M. von Unger, I.M. Emme, and B.W. Griscom. 2020. The Role of Soil Carbon in Natural Climate Solutions. Nature Sustainability. Vol. 3. p. 391–398.

Congressional Budget Office. 2008. Policy Options for Reducing CO_2 Emissions, Congressional Budget Office study. cbo.gov/doc.cfm?index=8934

Griscom, B., et al. 2017. Natural Climate Solutions. Proceedings of the National Academy of Science, Vol. 114. p. 11645-11650. pnas.org/content/pnas/114/44/11645.full.pdf

Indigo, 2021. Carbon by Indigo. indigoag.com/for-farmers

Intergovernmental Panel on Climate Change (IPCC). 2021. Climate Change 2021: The Physical Science Basis, Summary for Policymakers. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Mazza, Patrick. 2008. Growing Sustainable Biofuels—Common Sense on Biofuels, Part 2. Climate Solutions (online). climatesolutions.org/article/1590119179-growing-sustainable-biofuels-common-sense-biofuels-part-2

Natural Resources Conservation Service (NRCS). 2014. Conservation Practice Standard: Cover Crop. nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1263176.pdf

United States Department of Agriculture (USDA). 2021. Action Plan for Climate Adaptation and Resilience. sustainability.gov/pdfs/usda-2021-cap.pdf

United States Environmental Protection Agency (EPA). 2021. Inventory of U.S. Greenhouse Gas Emissions, 1990-2019. EPA 430-R-21- 005. pa.gov/sites/default/files/2021-04/documents/us-ghg-inventory-2021-main-text.pdf?VersionId=yu89kg1O2qP754CdR8Qmyn4RRWc5iodZ

United States (U.S.) Global Change Research Program. 2018. Fourth National Climate Assessment. nca2018.globalchange.gov/downloads/NCA4_2018_FullReport.pdf

Further Resources

Center for Climate and Energy Solutions, c2es.org

Climate Friendly Farming. Washington State University Center for Sustaining Agriculture and Natural Resources. csanr.wsu.edu/program-areas/climate-friendly-farming

Increasing Soil Health and Sequestering Carbon in Agricultural Soils: A Natural Climate Solution. Izaak Walton League of America and National Wildlife Federation. iwla.org/soils-agriculture/soilhealthreport

Agriculture Soil Carbon Credits: making sense of protocols for carbon sequestration and net greenhouse gas removals. Environmental Defense Fund. edf.org/sites/default/files/content/agricultural-soil-carbon-credits-protocol-synthesis.pdf

ATTRA Resources

Agroforestry

Perspectives on Agroforestry with Rowan Reid, Part I. 2021. attra.ncat.org/episode-187-perspectives-on-agroforestry-with-rowan-reid-part-1

Perspectives on Agroforestry with Rowan Reid, Part II. 2021. attra.ncat.org/episode-188-perspectives-on-agroforestry-with-rowan-reid-part-2

Cover Crops

Overview of Cover Crops and Green Manures attra.ncat.org/product/overview-of-cover-crops-and-green-manures

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